BRAND EVN Receiver

Status Report to the TOG

Walter Alef on behalf of the BRAND team

WHAT IS A BRAND RECEIVER

“Digital” VLBI-receiver for the EVN (and other) telescopes

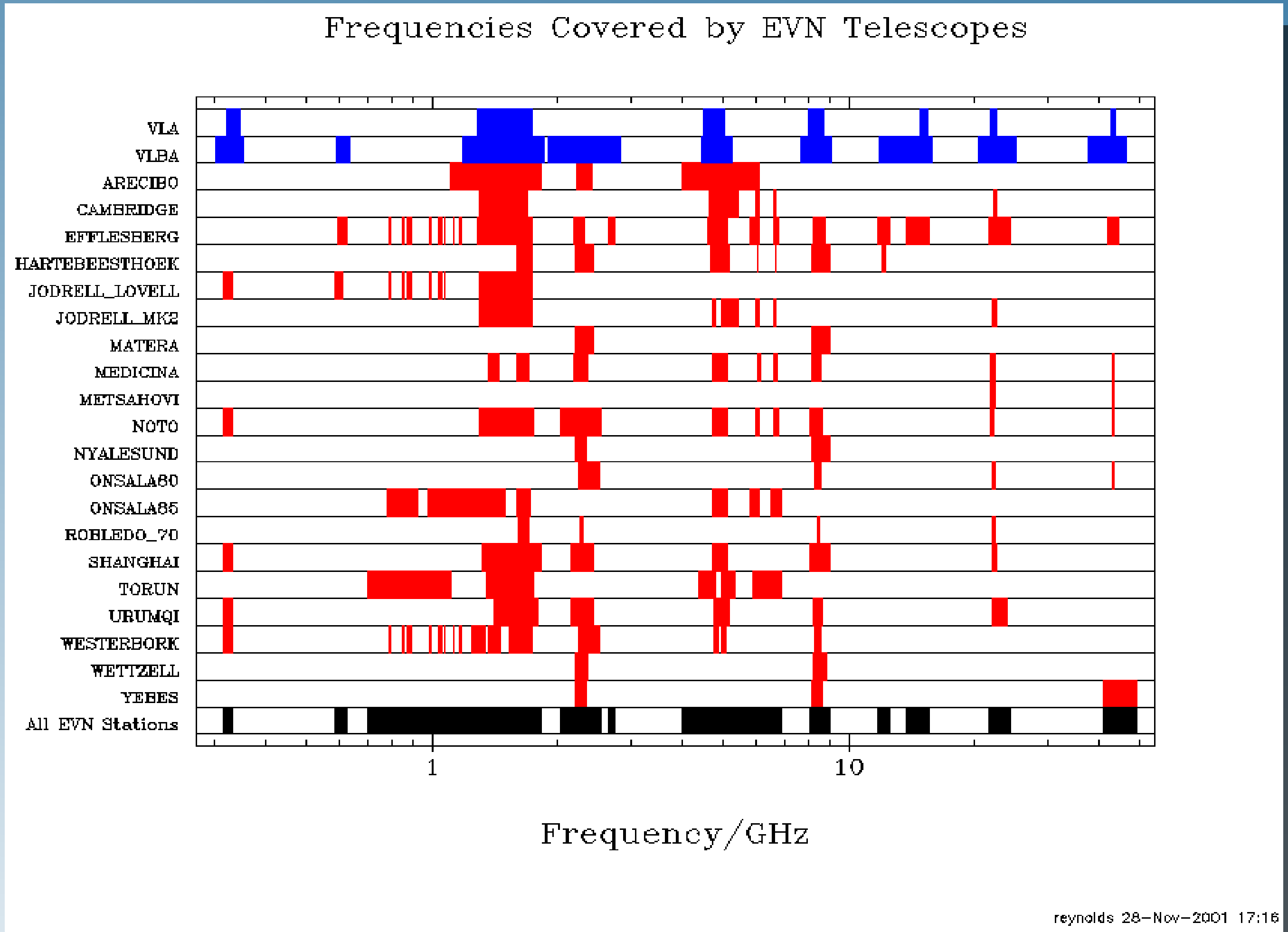
- Frequency range: 1.5 - 15.5 GHz
- Direct sampling – no down-conversion
- Sampling by a single sampler chip
- Data transport from receiver to backend via optical fibers
  - Will bypass IF limitations of legacy antennas

- Will allow multi-wavelength VLBI for astronomy
  - Fringe-fitting over whole band necessary (RadioNet JRA RINGS)
- Will extend VGOS band

BRAND JRA IN RADIONET

- BRAND EVN is a Joint Research Activity (JRA) in H2020 *Radionet*
  - Contract with the EU No: 730562
- Budget sponsored by the EU: ~1.5 M€ plus in-kind contributions by partners:
  - MPIfR, INAF/Noto, OSO, UAH/IGN, ASTRON, VUC
- Project started: January 2017
- Project ends: December 2020
- Prototype BRAND receiver for Effelsberg prime focus
  - Research for secondary focus feeds
  - Suitability study for other EVN antennas

EVN FREQUENCIES



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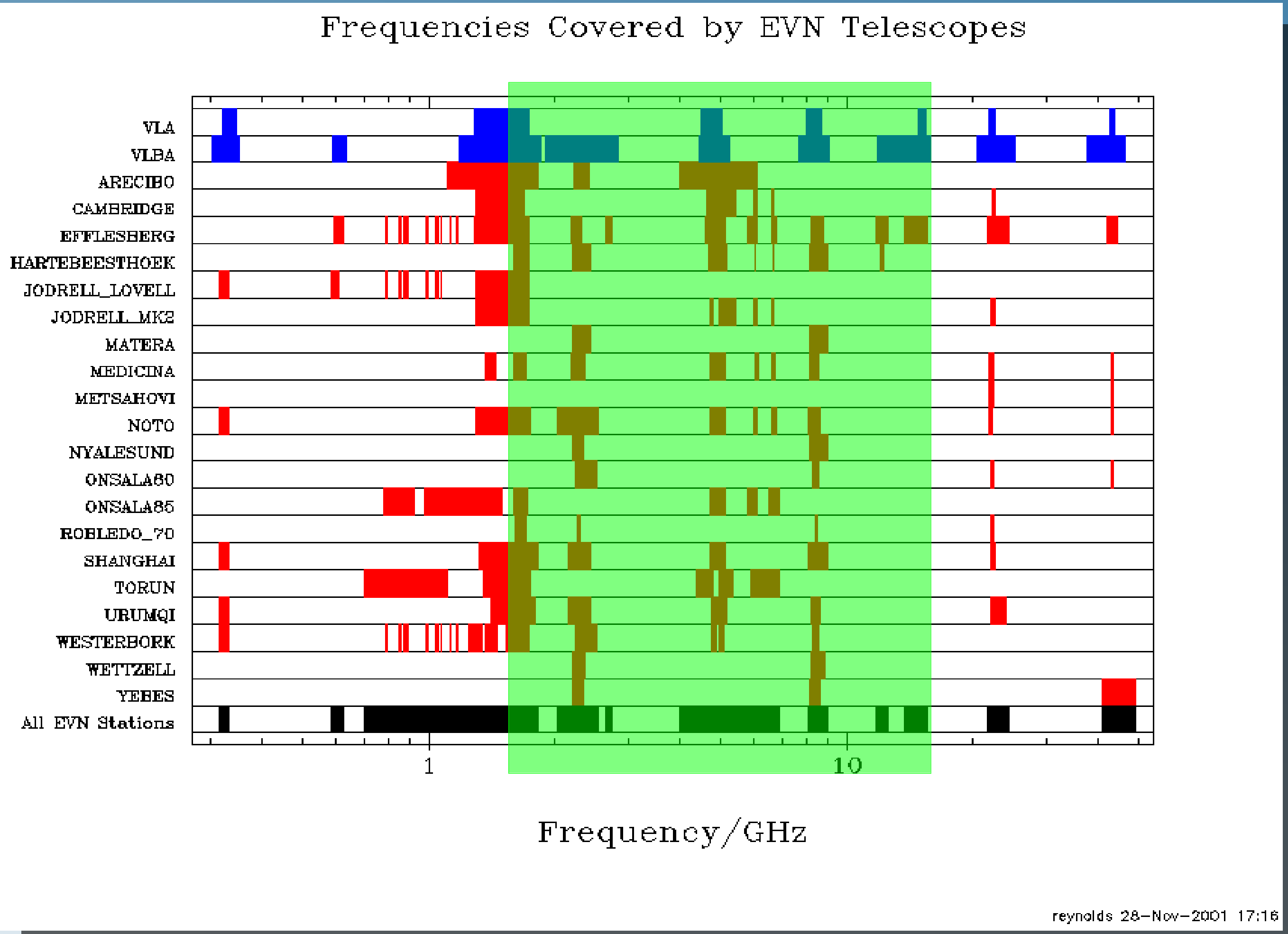
EVN FREQUENCIES VS. BRAND



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THE BRAND TEAM

W. Alef	MPIfR Bonn, Germany	Project Manager, VLBI test observations
G. Tuccari	INAF Noto & MPIfR Bonn	Project Engineer, BRAND architecture, HTSC filters, backend design, firmware, secondary focus study
J. Flygare, L. Pettersson	OSO, Sweden	Feed Horn, measurements of filter plus LNA
J.A. López-Pérez, F. Tercero, I. Malo, I. López-Fernández, C. Diez	IGN/UAH, Spain	LNAs, RFI, measurements of filter plus LNA, analogue polarisation conversion
C. Kasemann, M. Nalbach	MPIfR Bonn, Germany	Dewar, frontend integration, integration in Effelsberg tel.
M. Wunderlich, S. Dornbusch, A. Felke, H. Rottmann	MPIfR Bonn, Germany	Sampler & processing board layout, firmware, software, recording, correlation
J. Hargreaves, G. Schonderbeek, R. de Wilde	ASTRON, Netherlands	Digital polarisation conversion, software

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BRAND PROJECT STRUCTURE

Radionet board

Gino Tuccari
Project engineer

Walter Alef
Project manager

6.1 Feasibility survey (UAH-IGN)

Study of secondary focus feed

6.2 Frontend

- Primary focus feed (OSO)
- HTSC filters (INAF)
- LNA (UAH-IGN)
- Cryostat &Integration (MPIfR)

6.3 Backend

- Sampler (INAF, MPIfR)
- FPGA (INAF, MPIfR)
- Firmware (INAF, MPIfR, ASTRON)
- Integration (INAF,MPIfR)

6.4 Software

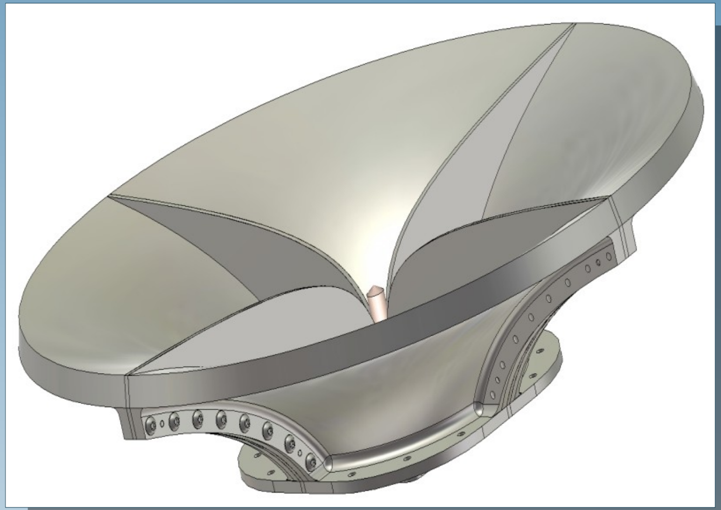
- Control (MPIfR, INAF)
- Recording (MPIfR)
- Correlation (MPIfR)

6.5 Integration

- Integration (all)
- Lab tests (all)
- Telescope test (all)

STATUS FEED HORN

- Feed horn designed by J. Flygare, M. Pantaleev, OSO
- Solution found for Effelsberg: QRFH feed with dielectric inset
- Antenna parameters:
  - Opening angle 160°
  - f/D = 0.3
- Feed characteristics (over whole band):
  - average aperture efficiency of 50%
  - input reflection better than -10 dB
- Feed manufactured and measured



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STATUS FEED HORN

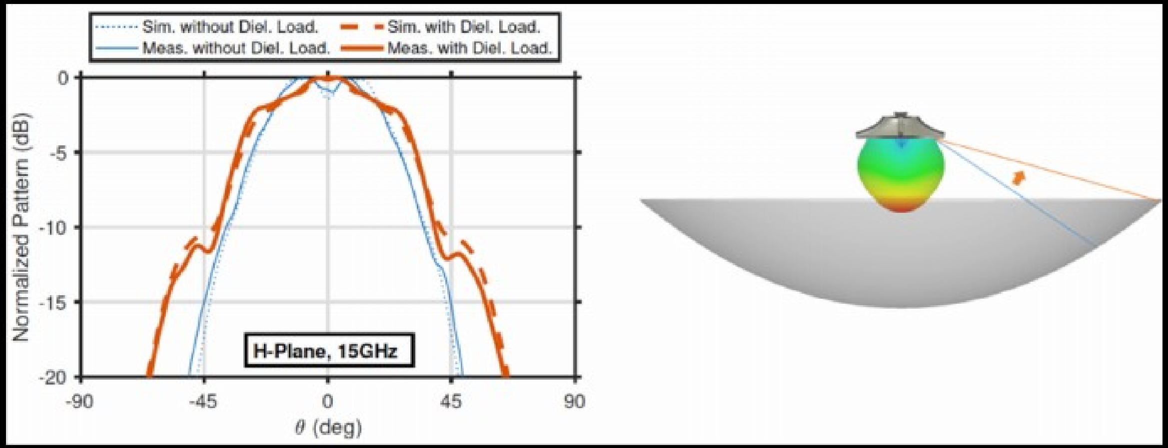
CHALMERS
UNIVERSITY OF TECHNOLOGY

QRFH

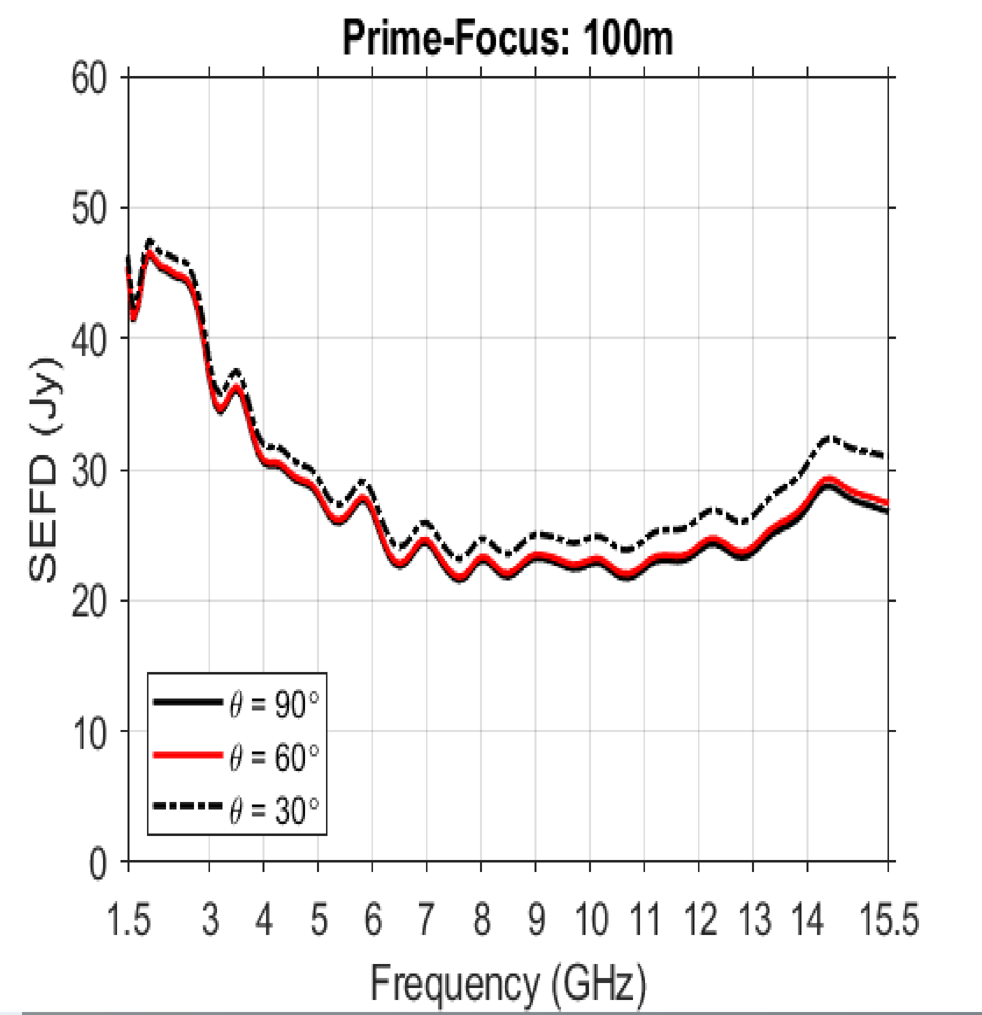
Dielectric

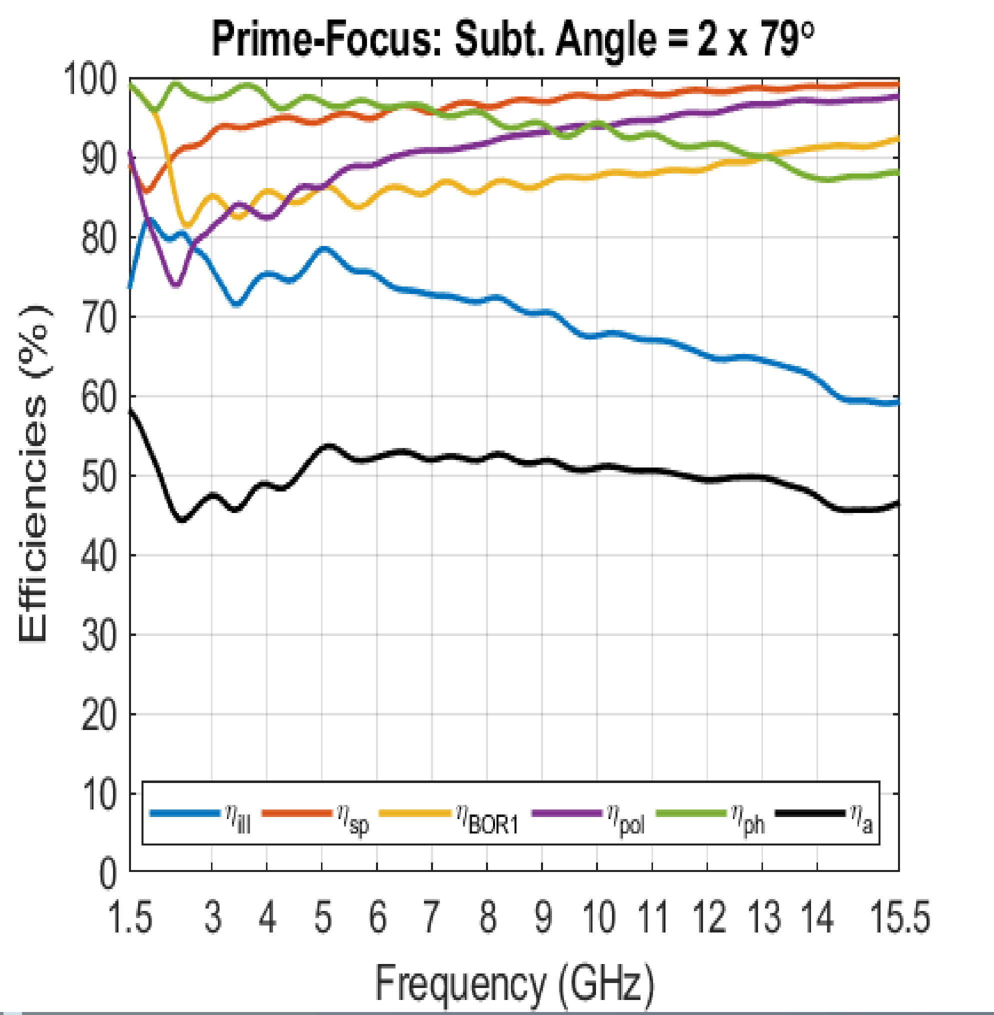
Improves @ "High-freq"

- *Illumination eff.*
- *Phase eff.*
- *Polarization eff.*



FEED HORN: SEFD & EFFICIENCY





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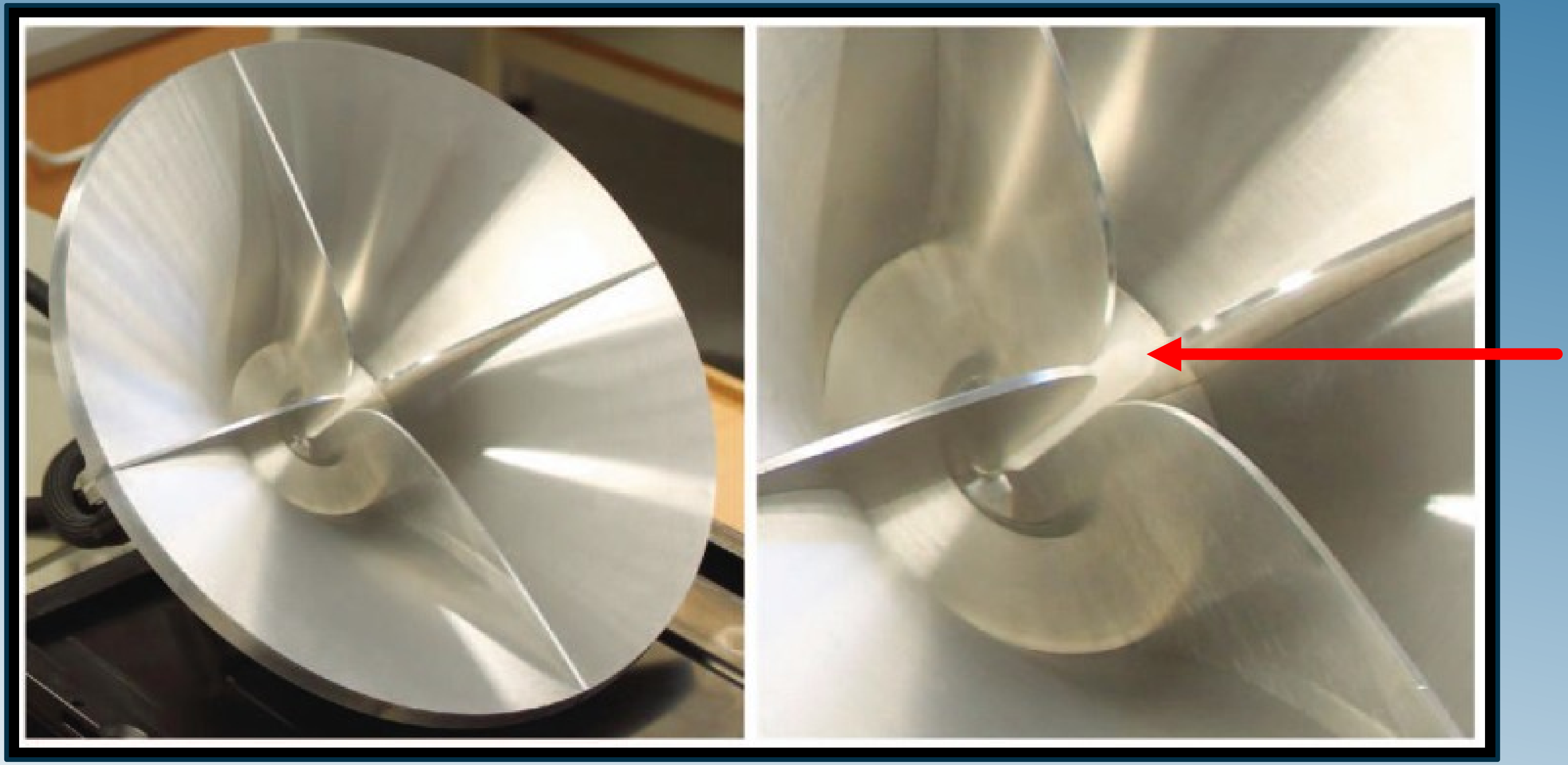
MANUFACTURED FEED HORN

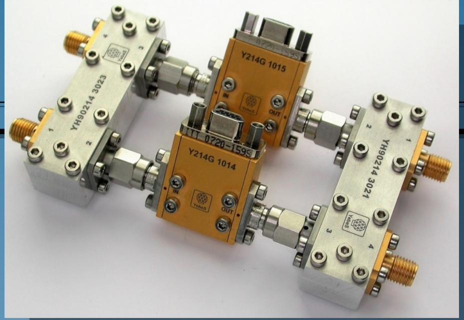


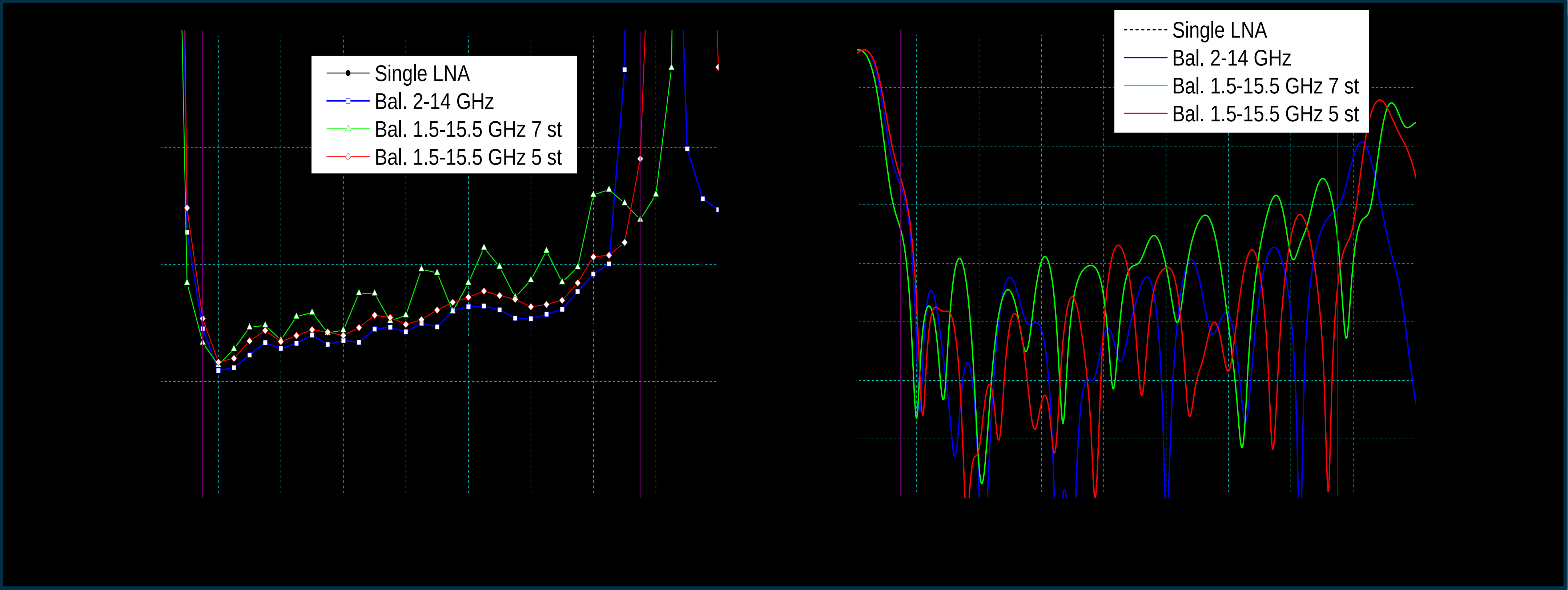
STATUS: HTSC FILTERS

- High Temperature Superconductor Filters, desired:
  - a high pass to cut below 1.5 GHz
  - 2 notches for strongest RFI → (1.8 GHz, 2.2 GHz)
  - A direction coupler for phase-cal & calibration
- Realized in 3 separate devices
  - **LNA** + **HTSC** filters + **coupler** measured at Onsala and Yebes

STATUS: LNA

- Best solution for extreme bandwidth found:
  - Balanced amplifier with 2 hybrids and 2 LNAs





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MEASUREMENTS OF FILTERS + LNA

2. Coupler + HPF + Notch + U-cable + LNA

- Complete chain measurement
- Bad coupler behaviour above 11.5 GHz.
- **Avg dTn = 4.1 K => Avg loss of Coupler+HPF+Notch = 0.64 dB (up to 11.5GHz)**

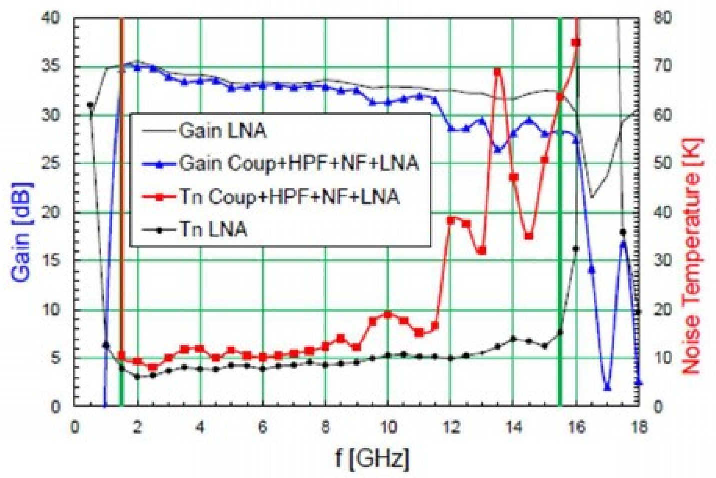

Figure 10: *Coupler + Highpass filter + Notch filter + "U" cable + Balanced amplifier noise and gain compared to balanced amplifier alone, revealing the bad behavior of the coupler above 11.5 GHz. Lower frequency resolution (0.5 GHz) was used in this case.*

High noise above 11.5 GHz due to coupler

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MEASUREMENTS OF FILTERS + LNA

3. HPF + Notch + U-cable + LNA

- Complete chain measurement without Coupler
- Filter resonances around 10 GHz and 14.5 GHz
- **Avg dTn = 2.13 K => Avg loss of HPF+Notch = 0.37 dB**

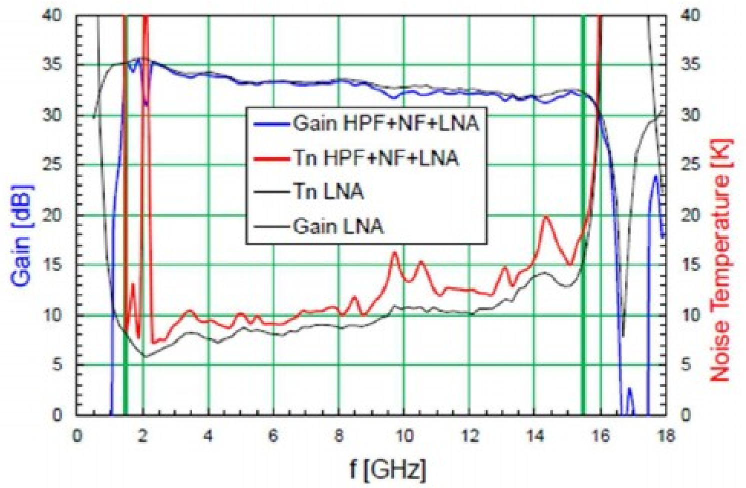

Figure 13: *Highpass filter + Notch filter + "U" cable + Balanced amplifier noise and gain compared to balanced amplifier alone. Note the various features introduced by the filters, best viewed in the figures corresponding to each filter.*

Yebes identified VGOS coupler to perform considerably better

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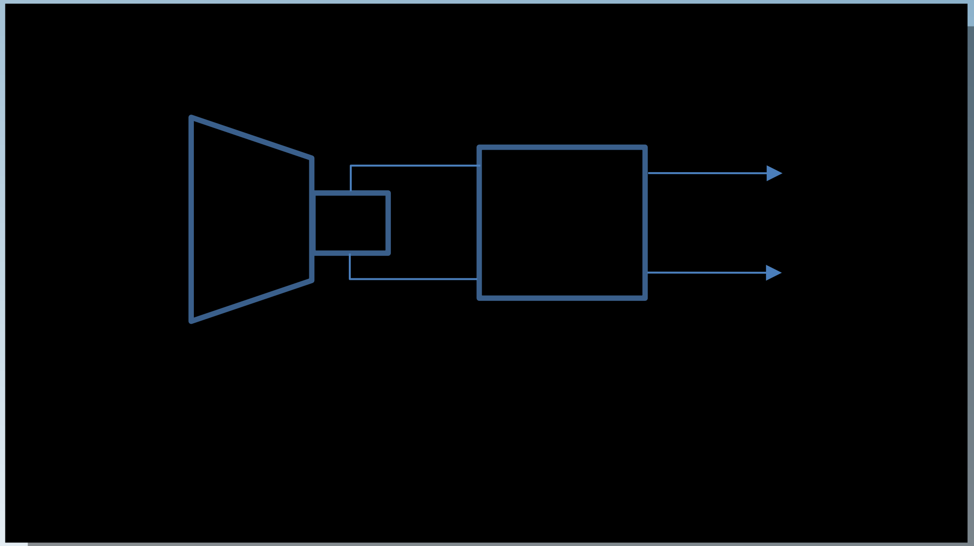
STATUS: POLARIZATION

- Linear to circular polarization conversion can be achieved using 3dB/90º hybrid (same hybrid as for balanced LNA)
- Average noise penalty across the band < 2.5 Kelvin
- Yebes development for BRAND and VGOS



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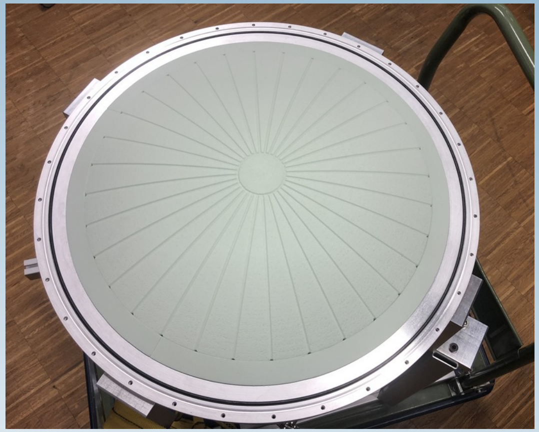
CRYOSTAT & RECEIVER BOX

- Building of the cryostat and other receiver components are much advanced – window Ø 80cm!
  - Simulation of the feed with dewar/window indicate no problems
  - Construction and integration nearly finished



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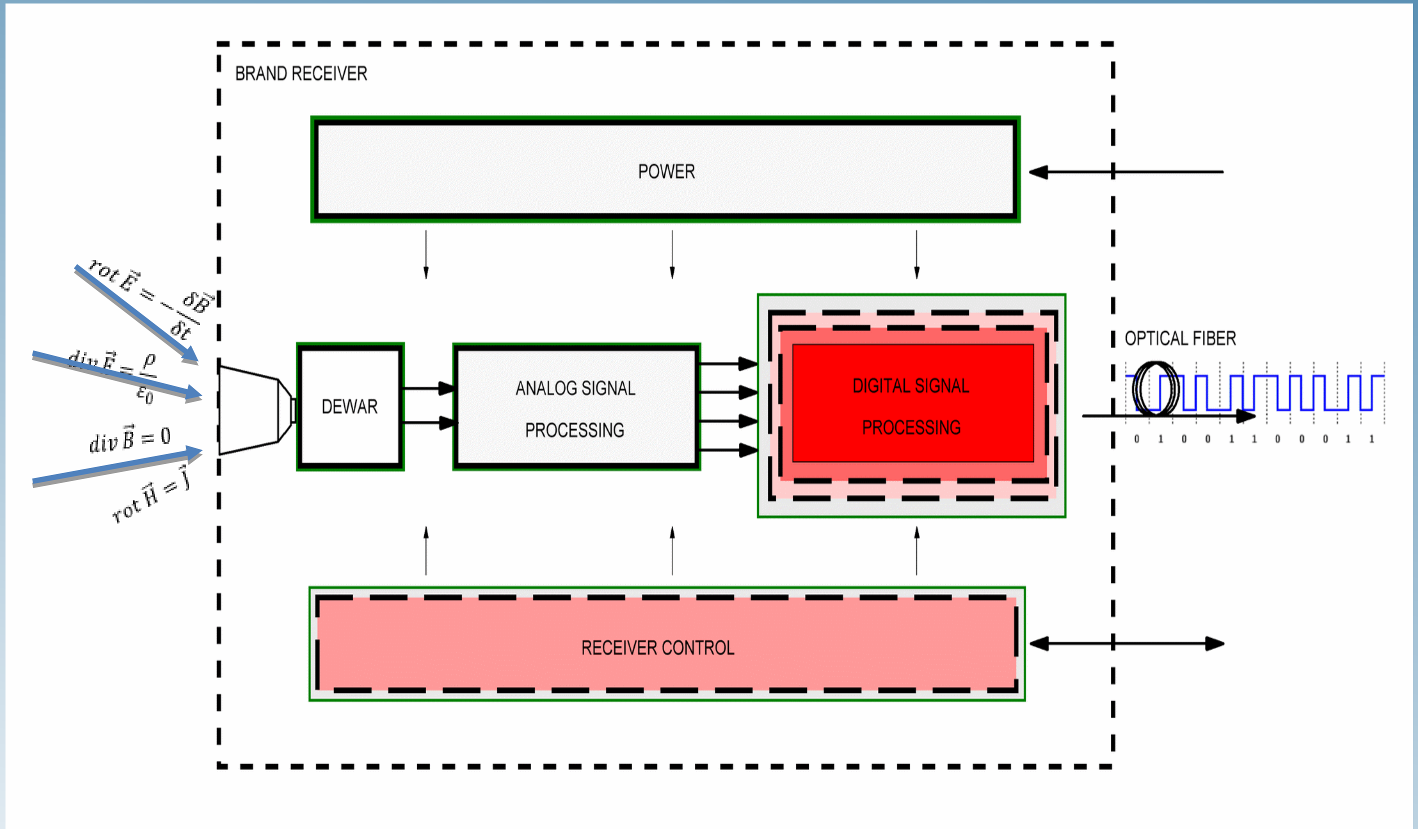
SIGNAL PROCESSING IN RECEIVER



- Receiver output: digital signal via optical fiber
- Strong shielding is required to avoid ‚self-inflicted‘ RFI (> 120 dB)
- Good temperature management is needed to get rid of the resulting heat

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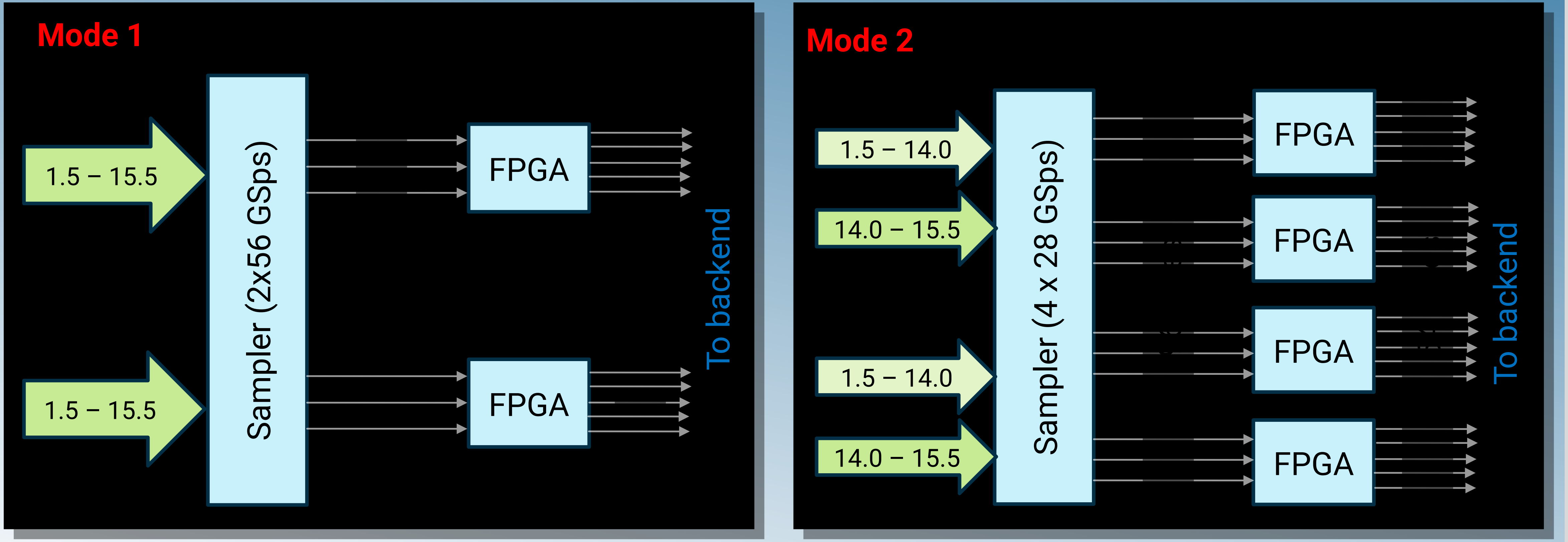
DIGITAL FRONTEND

- Sampler can process **128 GSps** (2 x 56 GSps or 4 x 28 GSps)
- Band formation of sampler output by FPGA



STATUS: DIGITAL FRONTEND

- The samplers were procured and tested successfully
- Purchase of an evaluation sampler board (software development)
- Board design finalized, produced and tested in MPIfR lab:
  - Will handle 2 polarizations and full bandwidth
  - 1 sampler w. 4 inputs @14GHz, 4 Xilinx Kintec Ultrascale FPGAs
  - 2x 0–14GHz, 2x 14–15.5 GHz in 2nd Nyquist zone
  - 2x 0–15.5GHz in 1st Nyquist zone (higher clock, 56 GSps)
  - PCB will work in the microwave regime: handles ~900 Gb/s
- 2 data streams from 2 ADCs in 1 chip extracted: 0-baseline test successful!
  - Sampler control all functional
  - Next: data transfer from sampler to FPGA ongoing

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DIFREND: DIGITAL FRONT-END BOARD *"COREAGLE"*

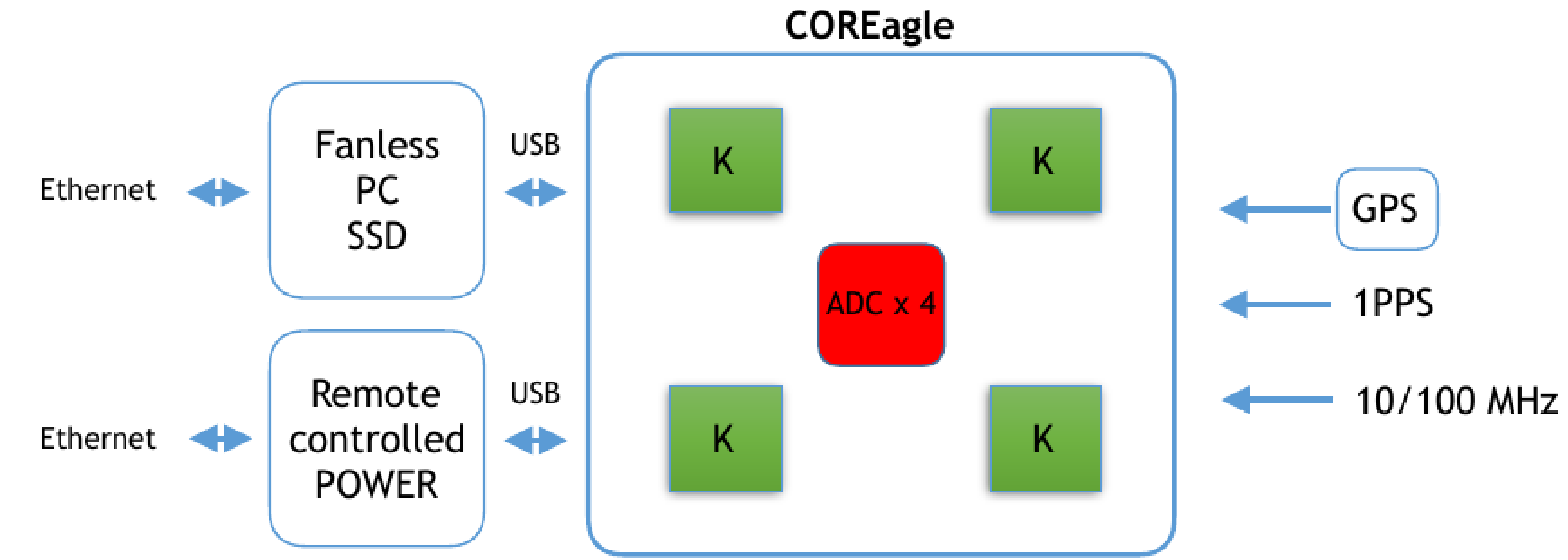
Dimensions:
30 x 40 cm

Layout:
22 Layers

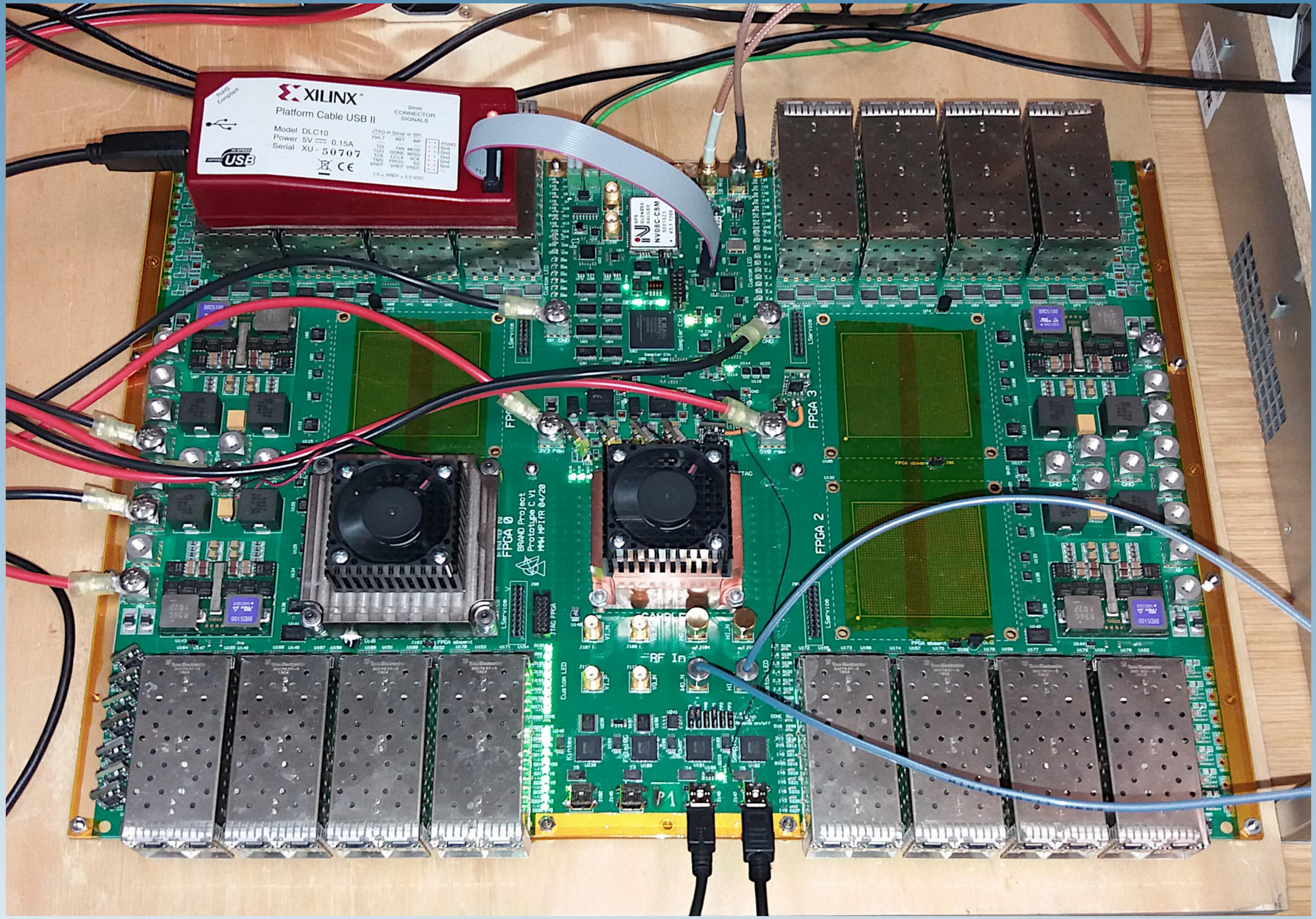
Sampling: (today)
8-bit @28/56 GHz
1 Tbps to FPGAs

Output from FPGAs:
64 x 10 Gbps compatible to DBBC3 digital input

BLOCK DIAGRAM DIGITAL FRONTEND "DIFREND"



Digital Frontend: connected



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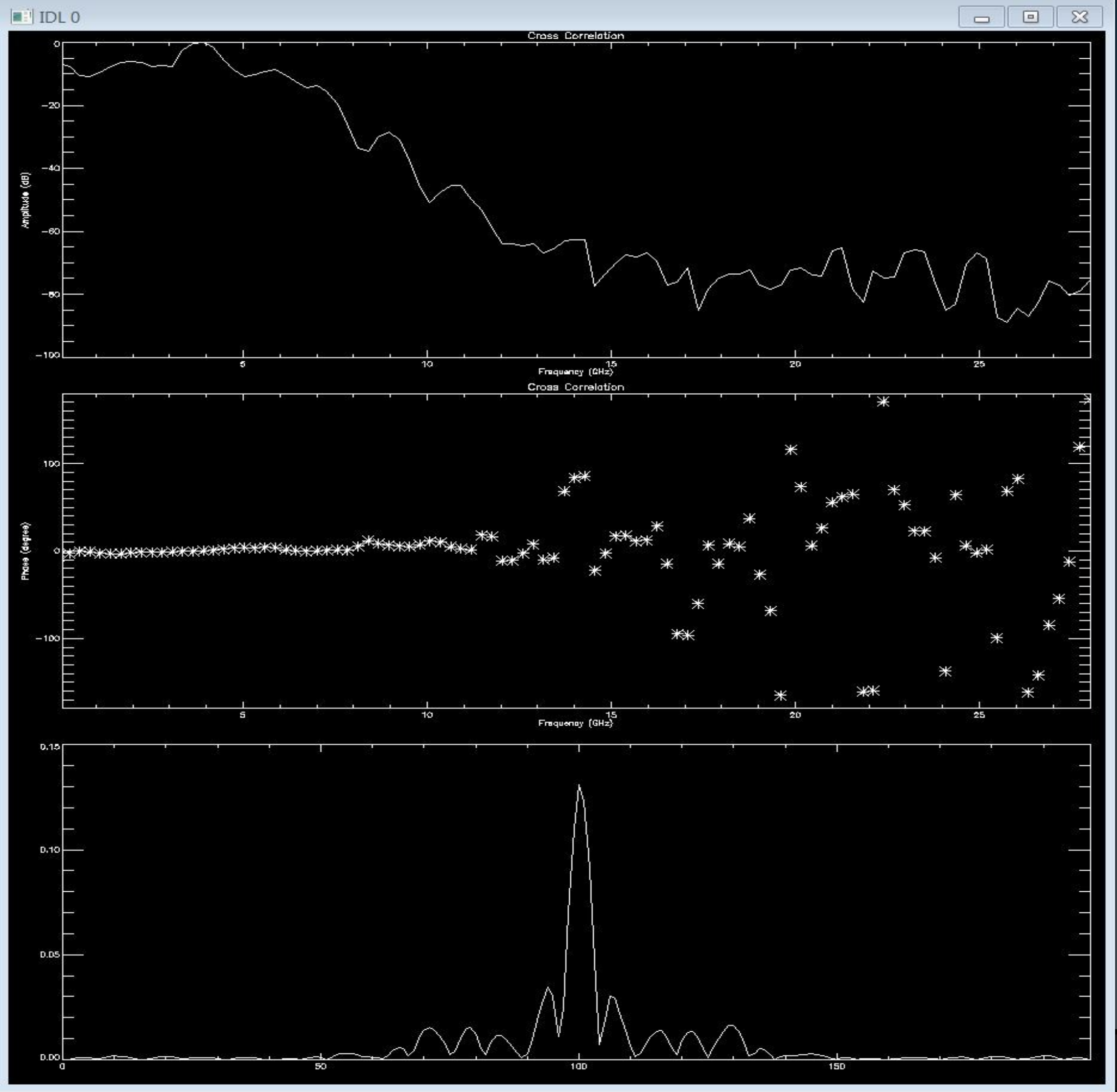
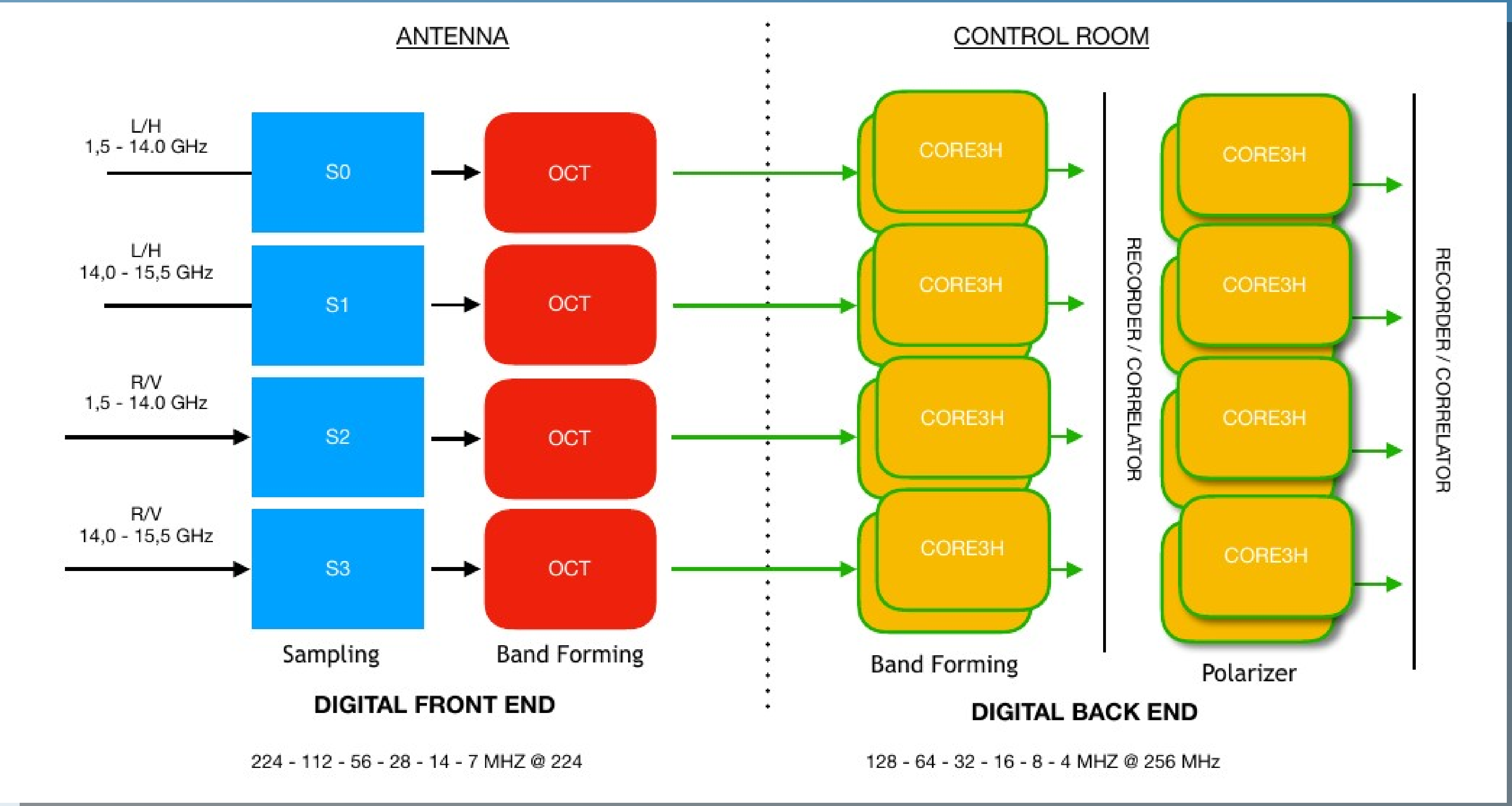
TESTS AND 0-BASELINE: DIGITAL FRONTEND

- Power and correct sequence at power-on ⇒ works
- Communication to Spartan3 control FPGA via USB ⇒ works
- Communication between control FPGA and sampler ⇒ works
- Programming of first big Kintex FPGA, tested with simple firmware ⇒ works
- Testing of control software in Python (derived from a library of Matlab scripts provided by the manufacturer of the sampler) ⇒ works
- Recording tests (snapshots) using internal storage in the sampler ⇒ works
- Testing sampler with tone injection in the range 0 to 20 GHz. Sampling with 56 GSps to test the full bandwidth ⇒ works
- Testing with broad-band noise using own noise generator ⇒ works
- Zero baseline test between 2 ADCs of the same sampler chip ⇒ Fringes!

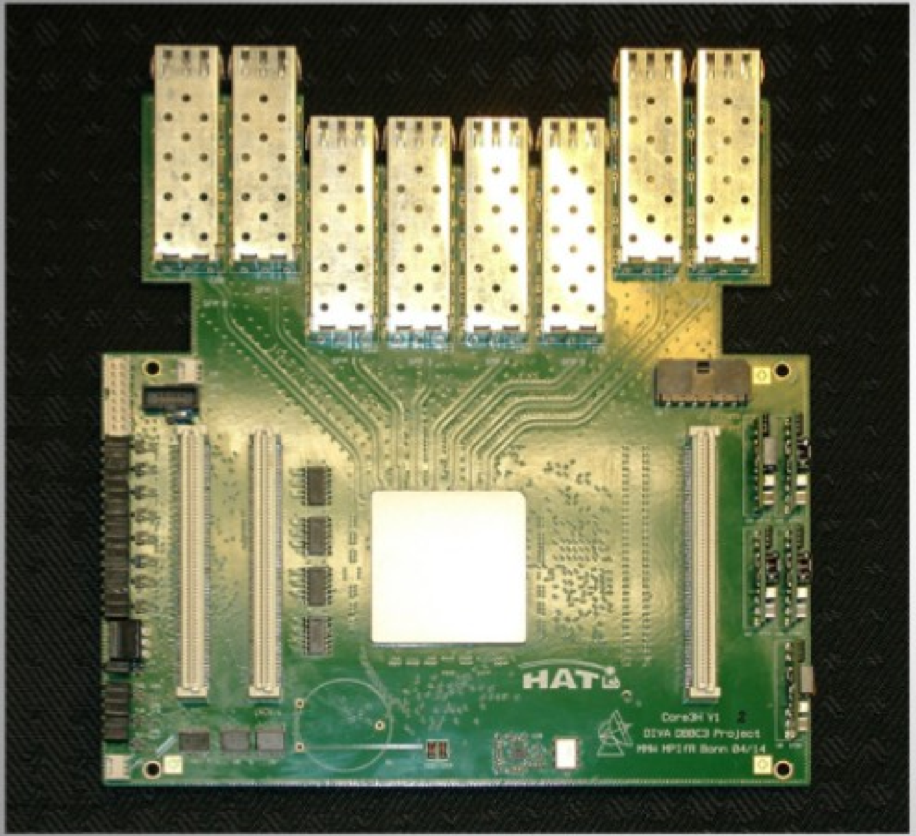


SIGNAL FLOW FRONTEND TO BACKEND



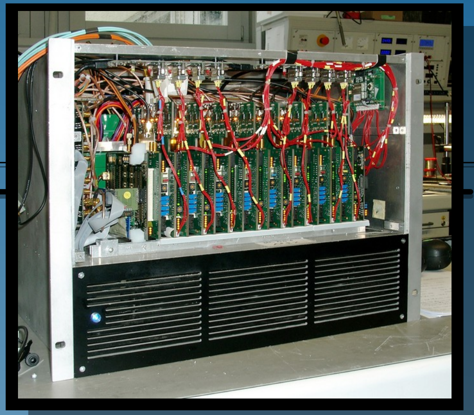
BACKEND: MODIFIED DBBC3

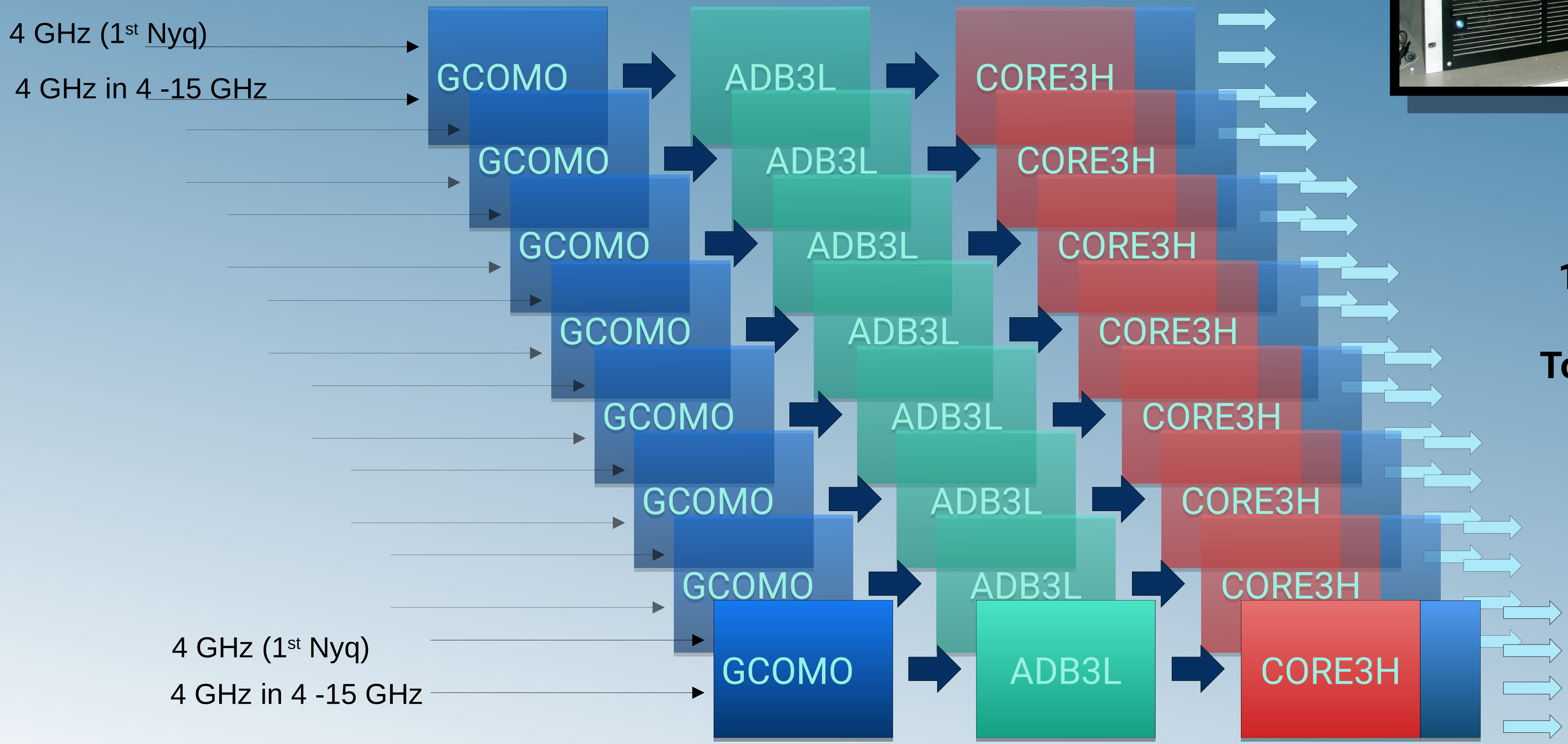
CORE3H



- Input bus: **HSI / HSI2** (128 bit differential)
- Input sampling representation: **10 bit**
- Max Input bandwidth : **4 GHz**
- Processing capability: **DSC, OCT, DDC**
- Max Output: **8 x 10GE SFP+**
- Network Input: **8 x 10GE SFP+**

BACKEND: MODIFIED DBBC3





128 Gbps

To recorders

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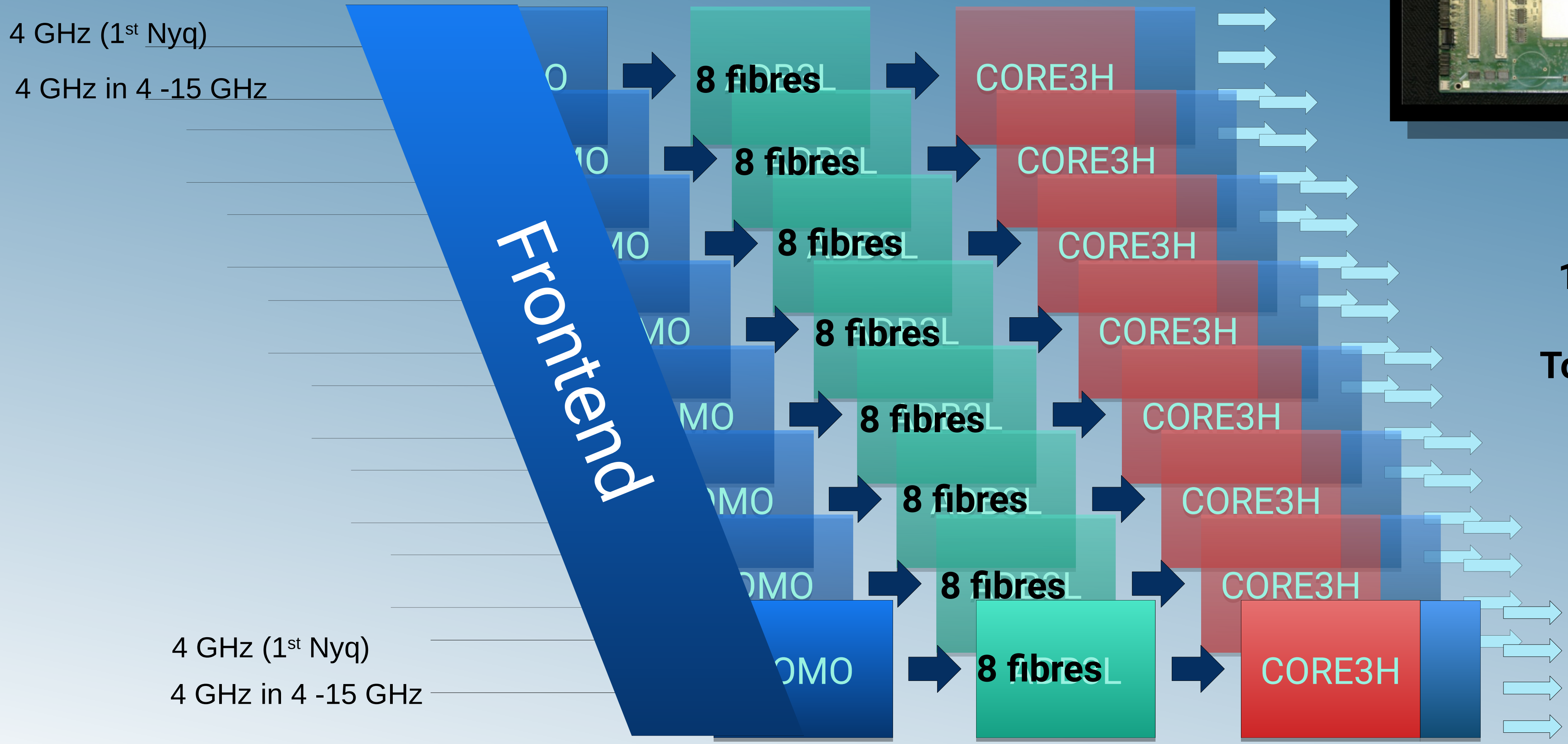
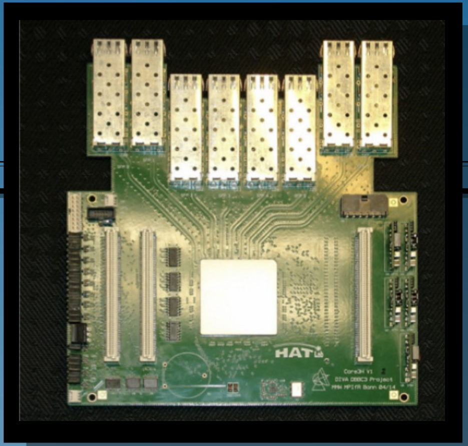
BACKEND: MODIFIED DBBC3





128 Gbps

To recorders

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STATUS: FIRMWARE

- Software for initialization and calibration of sampler chip (ready and tested)
- Interface sampler with FPGA and data reconstruction
  – being tested and debugged
- Band selection and first data processing:
  - OCT (arbitrary band selection) and DDC (digital downconverter)
    – DDC and OCT to be tested
- Ethernet data from frontend to DBBC3 (VDIF) – to be tested
- Further channelization in DBBC3: exists – tests
- Modifications needed for bi-directional transceiver use
- Polarization conversion (digital; ASTRON) – ready

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INTEGRATION & TESTING

- Integration is ongoing at MPIfR
- Testing will be in the lab (limited), on the telescope and with VLBI observation – preferably with
  - VGOS antennas
  - Selected EVN telescopes
  - VLBA (test 15 GHz)
- BRAND prototype ready with fringes not before end of 2020 due to Corona-Related delays. Current best estimate summer 2021.

  With present Covid-19 situation: more delays

Thank you!

Any questions?